

Heat as a tracer to examine streambed hydraulic conductance near the Russian River Bank Filtration Facility, Sonoma County, CA (USA)

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Extended Abstract

Both the measurement of temperature and the simulation of heat and water transport have benefited from significant recent advances in data acquisition and computer resources. This has afforded the opportunity for routine use of heat as a tracer in a variety of hydrological regimes. Heat is particularly well suited for investigations of stream/groundwater exchanges. Dynamic temperature patterns between the stream and underlying sediments are typical, due to large stream surface area to volume ratios relative to other surfacewater bodies. Heat is a naturally occurring tracer, free from (real or perceived) issues of contamination associated with use of chemical tracers in stream environments. The use of heat as a tracer relies on the measurement of temperature gradients, and temperature is an extremely robust parameter to monitor. Temperature data is immediately available as opposed to chemical tracers, which often require significant laboratory analysis. In this work, we report on the progress in the use of heat as a tracer to determine the hydraulic conductance of the streambed along the middle reaches of the Russian River, located west of Santa Rosa, CA. The general hydrological setting is described and the unique manner in which the water resources are managed in an environment of increasing population, a rapid shift to agricultural crops requiring more irrigation, and a series of fishery related mandates.

Ground water adjacent to the Russian River in Sonoma County, CA, is the primary source of drinking water pumped to Sonoma County Water Agency (SCWA) treatment facilities. This ground-water resource is superior to direct surface-water options, because experience has demonstrated that water extracted from the alluvial aquifer requires substantially less treatment than water extracted directly from the river, tributaries, or reservoirs. From late spring to early winter, SCWA erects an inflatable dam to raise the river stage and passively recharge the alluvial aquifer. The raised stage permits diversion of river water to a series of recharge ponds located upstream of the dam along the river. This results in enhanced extraction efficiency from water-supply wells situated along this reach of river. Production from these wells typically is reduced by 75% when the dam and recharge ponds are out of operation. Emerging issues, including fish habitat concerns and optimization of water resources management, indicate that a quantitative model should be developed to accurately represent stream/ground-water exchanges in the region of the watershed encompassing the inflatable dam. Improved scheduling of dam and recharge pond operations, as well as supply well pumping patterns would be aided by the development of a proven ground-water model for this region of the watershed. Successful development of a model requires that key hydraulic parameters be identified, including the spatial and temporal pattern of river conductance. Several tools are available to estimate these hydraulic parameters, such as pumping tests and chemical

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tracers. Some pumping tests have been performed; however, introduced chemical tracers are not an option for the Russian River, due to environmental and esthetic concerns.

In Phase I of the Russian River research, a series of observation wells were instrumented for water-levels and ground-water temperatures for comparison with river stage and surface-water temperatures. Observed temperatures are being used to optimize simulated temperature from VS2DH (a heat and ground-water transport simulation model), to predict the hydraulic conductivity at specific locations along this reach of the river.

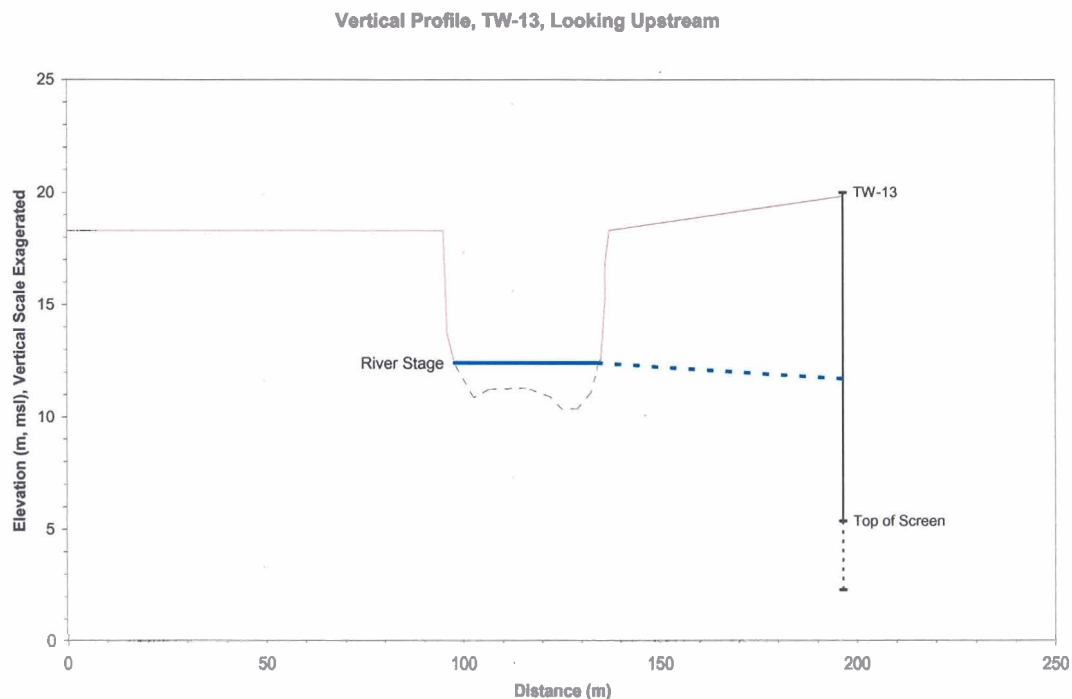


Figure 1 – The cross-section of the Russian River at Observation Well TW-13. The stream stage and ground-water level represent typical low streamflow conditions, which occur in Northern California in the June through October period.

Twelve observation wells along the bank of the Russian River are installed at approximately even spacing from 1 km below the RBF facility to a comparable distance upstream of the facility. Figure 1 gives an example river cross-section, depicting the banks, the river stage, the transient streambed profile, the location of the observation well, and the ground-water elevation. Temperature is continuously monitored at 30 minute intervals in the river and the observations well. This data is used to inversely fit simulated to observed ground-water temperatures using VS2DH. The best-fit results yield a ground-water flux and a streambed hydraulic conductivity, K . Figure 2 shows the best-fit simulated ground-water temperatures compared with the observed (measured) ground-water temperatures for TW-13, along with an example of an overestimate and an underestimate for K values. This clear sensitivity of temperature to hydraulic parameters

is a primary reason why the use of heat as a tracer of stream exchanges with ground water is emerging as a power hydrological tool.

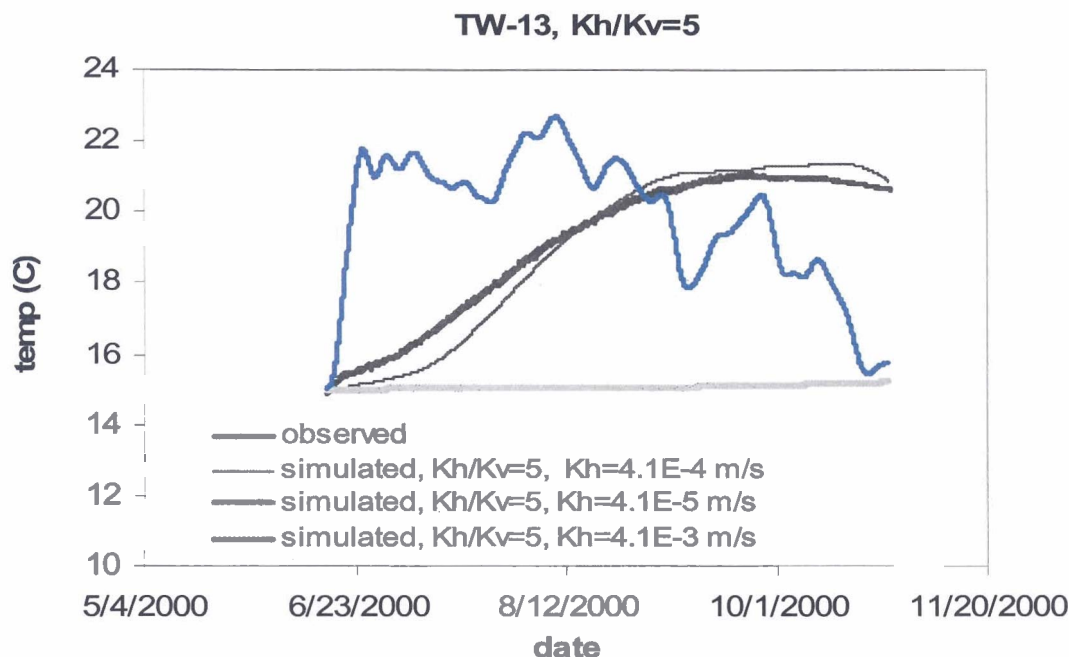


Figure 2 – Ground-water temperatures at an observation well (TW-13) next to the Russian River. The observed (measured) temperature is compared to VS2DH simulated temperatures for a high, low, and best-fit streambed hydraulic conductivity (K) estimates, where a horizontal (K_h) of 4.1×10^{-4} m/s represents the best fit, with a horizontal to vertical ratio of 5.

In Phase II of the research, more intensive instrumentation was installed near Collector Wells #1 and #2 of the RBF facility to examine streambed hydraulic processes in more detail in the immediate vicinity of the collector well radials (laterals). Figure 3 depicts a general cross-section at the collector wells, with a conceptualization of the zones of saturation beneath the streambed. Temperature and other parameters are being collected at the RBF facility. A detailed 3-D heat and ground-water transport simulation model, TOUGH2, is being used to analyze these thermal and hydraulic results. The extent of this unsaturated region will be investigated as different parameters change, such as the pumping rate, streambed hydraulic conductivity, and stream stage. The model that is being developed is based on the region near Collector Wells #1 and #2 along the Russian River in Sonoma County, CA, but the geometry of the system has been simplified in this model. A schematic of the cross-section (side-view) and plan view of the model is shown in Figure 4. The numerical grid has a finer resolution near the wells, so that the individual laterals can be simulated to examine radial impact on the unsaturated zone. The model is sufficiently flexible to simulated temporal changes in hydraulic conductivity to represent the transient formation of clogging layers in the streambed.

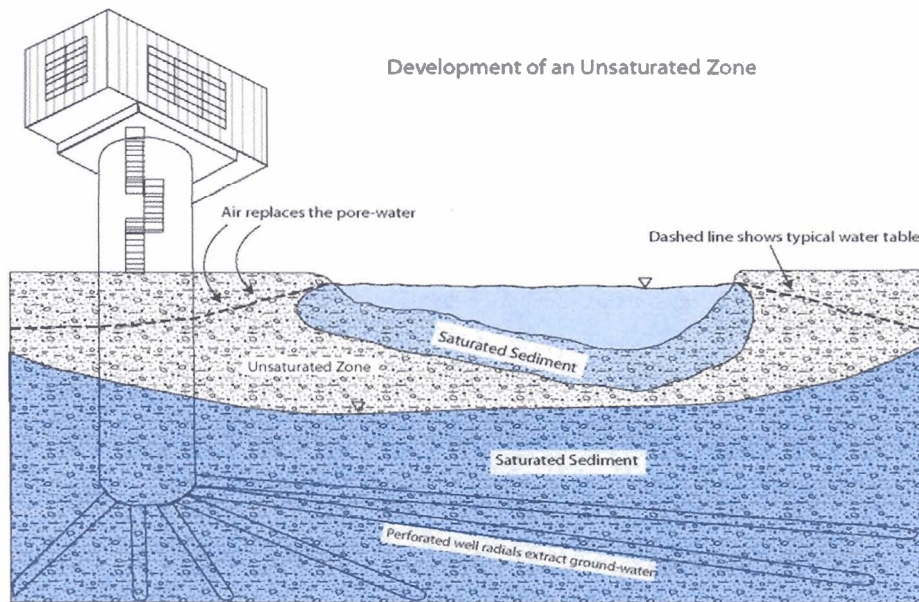


Figure 3 – A hypothetical cross-sectional view of the general pattern of unsaturated and saturated zones beneath the Russian River induced by the RBF facility radial (lateral) collector array.

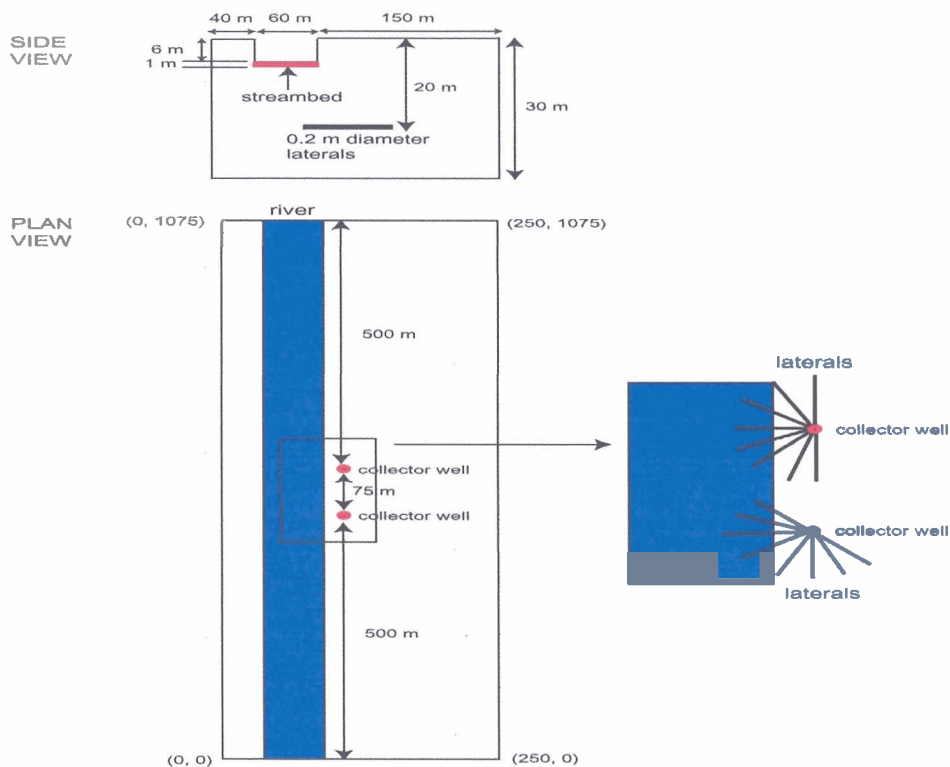


Figure 4 – A cross-sectional (side-view) and plan view of the conceptual frame for development of a 3-D Tough2 model to heat and ground-water flow near the RBF facility.